



Scale of Monitoring Influences Interpretation of Stream Habitat Restoration Results for Juvenile Chinook Salmon

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Abstract

Stream habitat restoration in the Entiat River, Washington, has increased juvenile Chinook abundance in pools with engineered logjams (ELJs); however, high spatial, temporal, and inter-species variation complicates distinguishing treatment effects between restored and unrestored habitat. Here we show that the scale of post restoration effectiveness monitoring can also be a confounding factor in such studies. In three stream reaches, we conducted snorkel surveys of (1) spatially randomized untreated habitat in which we also randomized survey area, and (2) restored (ELJ) habitat that included varying amounts of the surrounding stream area. Although we regularly observed more young-of-the-year Chinook salmon in restored than in unrestored habitat, this effect was very localized. After controlling for reach effects, fish density in untreated habitat was not affected by proximity to ELJs. Increasing the survey area increased total fish abundance, however, fish density decreased regardless of habitat type, indicating that ELJ structures did not necessarily increase fish abundance at the whole-reach scale. Specifically, increasing the survey area around a pool created by an ELJ by two to three times the restored pool area resulted in density measurements indistinguishable from unrestored habitat surveys. We conclude that whole-reach scale effectiveness monitoring surveys may give misleading results that dilute the effect of ELJs; therefore, monitoring should match the scale of specific restoration treatments.

Keywords: Habitat capacity, restoration, engineered logjam, Chinook salmon, Entiat River.

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Introduction

To return Pacific salmon populations to historical levels, recovery actions are focused on each of their major life stages, with much effort directed toward the juvenile stages in streams (Roni et al. 2010). Habitat restoration techniques include the addition of instream structures such as rock barbs, engineered logjams (ELJs), or fish passage structures; the removal of levees, dams, and other disruptions that block access; bank stabilization or replanting; beaver introduction; rechannelization; side channel and floodplain restoration; sediment reduction or addition; and flow augmentation (Roni et al. 2002, 2008). In the interior Columbia River basin (ICRB), several subbasins are monitored for fish population status and trends (McClure et al. 2003), and managers have, thus far, implemented restoration projects in a few of these subbasins to improve rearing habitat for subyearling Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*). Both species have evolutionarily significant subpopulations throughout the ICRB listed as threatened or endangered under the Endangered Species Act.

To have the highest probability of successful recovery within a subbasin, the recommended approach is a combination of restoration techniques throughout the watershed, not just on a focused section (Beechie et al. 2010, Roni et al. 2008). This has led to the establishment of programs known as intensively monitored watersheds (IMWs) (PNAMP 2005). In IMWs, rigorous effectiveness monitoring is undertaken in conjunction with restoration actions (Bennett et al. 2016). Whole reaches within subbasins may be targeted for one or more types of restoration, and monitoring includes assessments of restoration efficacy in terms of biological responses (Block et al. 2001). Monitoring of IMWs is often focused on whether restoration actions went according to scheduling and design; whether there has been a change to the long-term status and trends of the subpopulation as a whole; or to evaluate the overall biological effectiveness of restoration with a response detected at the project, reach, or population scales (Roni et al. 2013, 2018b).

Use of large wood or other material to build ELJs is widely implemented across the ICRB region (Hillman et al. 2016, Roni et al. 2015). ELJs are designed to diversify channel morphology via hydrologic processes (Davidson and Eaton 2013), increase pool frequency for rearing (Roni et al. 2010), provide cover (Bond and Lake 2003), and increase macroinvertebrate prey availability (e.g., Hilderbrand et al. 1997, Kail et al. 2007). Multiple ELJs at different frequencies may be placed in a restoration reach depending on the results of assessments that weigh the hydrologic properties of the reach in question with likely fish responses. The recommended monitoring design is rigorous enough to detect changes in fish abundance at the reach scale because the whole reach is considered the unit of restoration (Roni et al. 2010). However, it may be necessary to consider past restoration effectiveness studies to determine the appropriate scale of a monitoring design.

Post-restoration effectiveness monitoring is challenging owing to the difficulty of capturing temporally or spatially consistent responses in fish abundance, even with multiple treated and reference stream reaches (Polivka et al. 2015, Smokorowski and Pratt 2007, Whiteway et al. 2010). In many cases, small or no restoration effects are apparent (Hillman et al. 2016, Roni et al. 2008, Stranko et al. 2012), and even when responses are positive they can vary greatly by species, year, and time period within a rearing season (Polivka et al. 2015). This may not necessarily be because restoration projects are poorly designed, but because fish-habitat relationships are complex, particularly for salmon (Beechie et al. 2005, Bradford and Higgins 2001). This complexity can occur because good habitat is underused (Polivka 2005), or correlative analyses may overestimate the importance of habitat variables as predictors of fish abundance because correlation coefficients are weak (Lammert and Allan 1999, Shirvell 1989).

Polivka et al. (2015) showed that when fish abundance in pools created by ELJs is high, and fish abundance in untreated habitat in the same reach remains the same as in untreated reaches elsewhere, then overall capacity increases can be inferred to be the result of restoration in that reach. This method, however, requires separate surveys of treated and untreated habitat within a treated reach at a relatively small (microhabitat) scale. If effectiveness monitoring is conducted at the reach scale, as is the goal of many monitoring programs (Roni et al. 2013b, 2018a), total fish density will integrate all habitats combined (Beechie et al. 2005). Depending on the ratio of restored to unrestored area, the increased fish density in restored habitats might be diluted quickly, especially if the ELJs have very localized effects. Using three restored reaches in an IMW subbasin, we ask whether monitoring surveys at larger scales reduce the observed impact of specific restoration actions. Specifically, we ask: (1) Are the effects of restoration with ELJs on Chinook salmon density localized? (2) Does restoration with ELJs affect the Chinook abundance or density relationship with the survey area? (3) Does increasing the survey area around ELJs dilute the Chinook density measured at restoration structures?

Here we show that young-of-the-year Chinook salmon density was higher in pools created or restored with ELJs than in unrestored habitat, although with some among-site variation. However, a short distance from ELJs, fish density quickly declined to zero. Increasing the survey area increased the number of Chinook encountered, but decreased fish density, independent of whether the surveys included restored habitat. In fact, once the total area surveyed reached two to three times the area of the ELJ pool, total density was indistinguishable from unrestored habitat. Thus, we show that ELJ restoration has a very localized effect, and whole-reach surveys in treated reaches that include counts of fish from large sections of untreated habitat may fail to detect small increases in habitat capacity resulting from restoration.

Methods

Study Site

The Entiat River in north-central Washington, United States, is one of four major subbasins of the Upper Columbia River evolutionarily significant unit for Chinook salmon. Its headwaters are in the Cascade Mountains and run ~ 69 river km to its confluence with the Columbia River (river km 778; 49.6567 N, 120.2244 W), draining a watershed area of about 1085 km² (Bookter et al. 2009). Restoration began in 2005, with several projects implemented by 2008 when it was designated as an IMW (Sixta 2010). Three major geomorphic valley segments are in the Entiat River (Godaire et al. 2009). The lower valley segment (river km 0–26) is a high-gradient segment with large cobble substrate and laterally eroded finer particles of sand and gravel. Relatively fast-flowing water, given a slope of 1.04 percent, occupies an average wetted width of 25.4 m. Three reaches in the lower valley segment were selected for this study (fig. 1). The Milne reach (river km 4.5–5.1) was treated first in 2008 with 11 ELJ and rock structures, and again in 2014 with six ELJ structures. The Yakama reach (river km 4.0–4.3) and the Keystone reach (river km 2.4–2.7) were treated in 2014 with eight and six ELJs, respectively (fig. 1).

Surveys of Fish Abundance

We counted young-of-the-year Chinook salmon in both treated and untreated habitat in the Milne, Yakama, and Keystone reaches on separate days in July 2018 via snorkel surveys. Visibility in the Entiat River was very good, such that fish could be visually enumerated while snorkeling. The number and species of other fish observed were also recorded. In addition to surface area (m²) surveyed at each location, the water depth (m), current velocity (m/s), and temperature (°C) were recorded.

Untreated habitat was randomly selected by starting at the upstream end of each reach and following the method of Polivka et al. (2015). Fifteen untreated habitats were surveyed in the Milne reach, while ten untreated habitats were surveyed in each of the Yakama and Keystone reaches. The randomization procedure consisted of dividing the length of the reach (L) by 15 and using a random number generator to select a distance that ranged from 10 m to L/15 m to locate a subsequent survey point relative to the previous, thus the untreated habitat surveys were at least 10 m apart but could not fall outside the defined treatment reach. The survey took place on either the left or right river margin, selected via coin toss. Only margin habitat was surveyed because mid-channel surveys provide little additional information in other salmonid streams (Beechie et al. 2005), and the ELJs were built along the river margins.

At untreated habitat, the area to be surveyed was randomly generated from a range of 10 to 60 m² prior to field work. In addition to the physical habitat variables mentioned above, these surveys included measurements of the distance to the

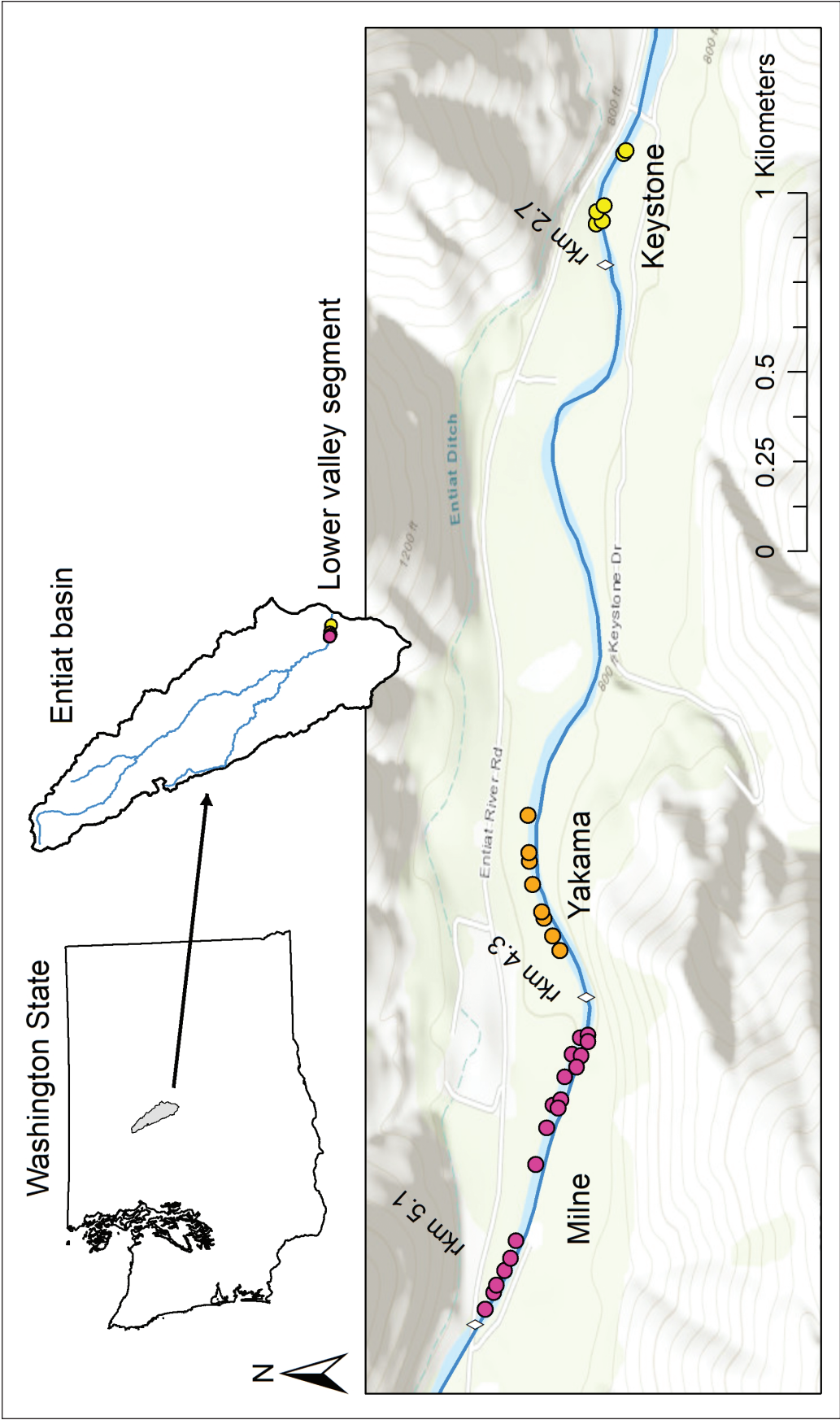


Figure 1—Map of study area in the Entiat River, Washington State, USA. Study reaches are Milne (magenta), Yakama (orange), and Keystone (yellow), with locations of engineered logjams (circles) and river kilometers (rkm) marked at the upstream end of each reach.

nearest ELJ, upstream or downstream, to evaluate specifically whether fish density in untreated habitat was affected by proximity to restoration structures. Treated habitat surveys were conducted at each pool created or restored by an ELJ. The survey area for each pool was randomly predetermined to be one, two, or three times the area of the ELJ pool.

Data Analysis

Localized restoration effects—

All fish-habitat relationships were analyzed using generalized linear models (GLMs). Although many species abundance-habitat relationships are manifestly nonlinear (e.g., James and McCulloch 1990, Olden and Jackson 2001), GLMs are still strong tools for quantification of ecological relationships (Guisan et al. 2002) and have proven to provide reasonable, robust descriptions of this study system (Polivka et al. 2015). To describe the relationship between Chinook density in untreated habitat and the distance of a survey point to the nearest ELJ, while incorporating the effect of varying the survey area, the GLM included all measured habitat variables (area, depth, current velocity, temperature) and reach effects. The survey area was log-transformed prior to the analysis. We also included interaction terms to determine whether any physical differences between survey points affected fish density. Because the response variable was fish density, we assumed a Gaussian error distribution. We tested the significance of terms using an ANOVA with χ^2 tests on terms in the *a priori* fitted model following the method of Polivka et al. (2015).

Restoration effects on abundance- and density-area relationships—

To analyze whether the relationship between either Chinook abundance or density and survey area differs in restored habitat vs. untreated habitat, we used a GLM relating total number of Chinook to all measured habitat characteristics, including the presence of ELJs. For fish abundance (counts), the model assumed a Poisson error distribution. After each model run, nonsignificant terms were removed, and the new model was tested. The best model was selected using the Akaike Information Criterion (AIC) (Burnham and Anderson 2002). When competing models differed by $\Delta\text{AIC} < 3$, the model with the fewest nonsignificant terms was selected. We used the same analysis procedure with fish density as the response variable, only assuming a Gaussian error distribution.

Increasing survey area effect on Chinook density—

To analyze the extent to which fish density at structures was affected by widening the survey area around a structure, we constructed GLMs to compare fish density across reaches and across the varying extent, or multiples (one to three times), of survey area relative to the dimensions of the pool associated with the structure. The best model was selected by AIC as described above.

Results

Localized Restoration Effects

Chinook density declined with distance to structure, but distance did not produce a strong effect in the model (table 1), suggesting that fish were very clustered in ELJ pools. The untreated habitats with high density were usually within 20 to 25 m of an ELJ pool, but other habitats the same distance from ELJ pools had zero fish (fig. 2). Densities in untreated habitats were correlated with slower current velocity, and measured density declined with increasing survey area. In untreated habitats, the Milne site had significantly higher fish density than in the Yakama or Keystone reaches (table 1).

Table 1—Deviance values and significance from analysis of variance (ANOVA) with χ^2 tests on the best fit generalized linear model, indicating significant variables determining density of young-of-the-year Chinook salmon in untreated habitat of varying area

	Coefficient	Degrees of freedom (df)	Deviance	Residual df	Residual deviance	P-value
Area	-	1	0.200	34	1.36	0.036
Reach	Milne	2	0.392	31	1.99	0.014
Distance to structure	-	1	0.170	33	2.38	0.053
Pool depth	+	1	0.130	30	1.86	0.091
Current velocity	-	1	0.305	29	1.56	0.010
Temperature	-	1	0.129	28	1.23	0.092

Analysis included data from all three study reaches and considered all measured physical habitat variables. Coefficients are derived from GLMs and represent positive (+) or negative (-) coefficients for physical variables, or significant categorical variables (i.e., reach). Fish density declines are marginally significantly with distance to structure, indicating localization of fish density.

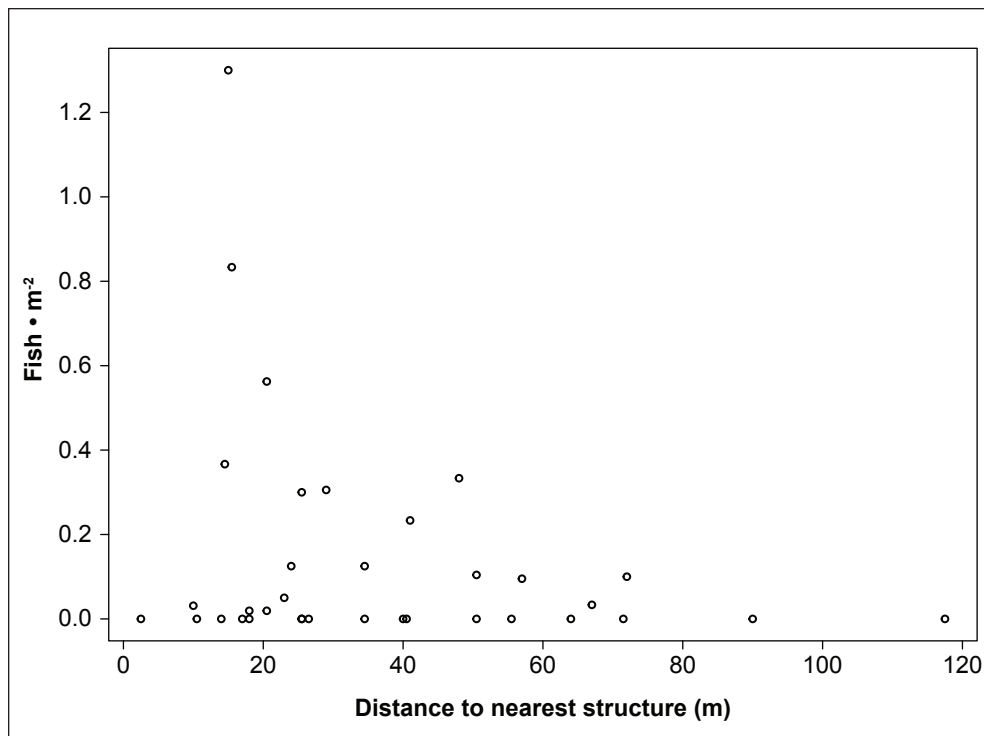


Figure 2—Density of young-of-the-year Chinook salmon observed in untreated habitat in randomly selected locations at increasing distances from the nearest engineered logjam structure from snorkel surveys conducted over varying area (10 to 60 m², randomly selected) at all three reaches combined.

Restoration effects on abundance- and density-area relationships—

More Chinook were observed in untreated habitat as survey area increased (fig. 3A); however, the presence of ELJs at pools did not affect the abundance-area relationship (table 2). Similarly, when only untreated habitat was considered, Chinook abundance in both habitat types combined was correlated with deeper, slower flowing water. The best model included a significant interaction between survey area and reach (table 2A), related to high total abundance at the Yakama reach with both habitat types combined. No interaction between reach and survey area resulted in no differences among reaches in the abundance-area relationship.

As area increased, density (fish/m²) decreased, again regardless of whether restoration structures were present at the habitat (fig. 3B; table 2). Thus, the rate at which more fish are encountered (fig. 3A) is not proportional to increases in area. This is also consistent with substantial decreases in density with increasing distance from an ELJ pool (fig. 2). Slower current velocity predicted Chinook density across both habitat types, but no other predictor was meaningful.

Table 2—Deviance values and significance from analysis of variance (ANOVA) with χ^2 tests on the best fit generalized linear model indicating significant variables determining abundance and density of young-of-the year Chinook salmon in restored pools and unrestored habitats of varying area in all three study reaches combined

	Coefficient	Degrees of freedom (df)	Deviance	Residual df	Residual deviance	P-value
Abundance:						
Area	+	1	40.57	64	583.28	<0.0001
Reach	Yakama	2	11.56	62	571.71	0.004
ELJ present	NS	1	0.026	59	372.06	0.873
Pool depth	+	1	8.11	61	563.60	0.004
Current velocity	-	1	191.52	60	372.08	<0.0001
Area × reach	NS	2	3.66	57	368.40	0.160
Density:						
Area	-	1	1.10	64	8.13	0.002
Reach	NS		2	0.036	60	6.94
ELJ present	NS	1	0.280	59	6.66	0.116
Pool depth	NS	1	0.109	63	8.02	0.328
Current velocity	-	1	1.04	62	6.98	0.003
Area × ELJ	NS	1	0.211	58	6.60	0.474

Note: Direction of association between fish abundance or density and model parameters indicated by (+/-), except where parameters are not significant (NS). ELJ = engineered logjam.

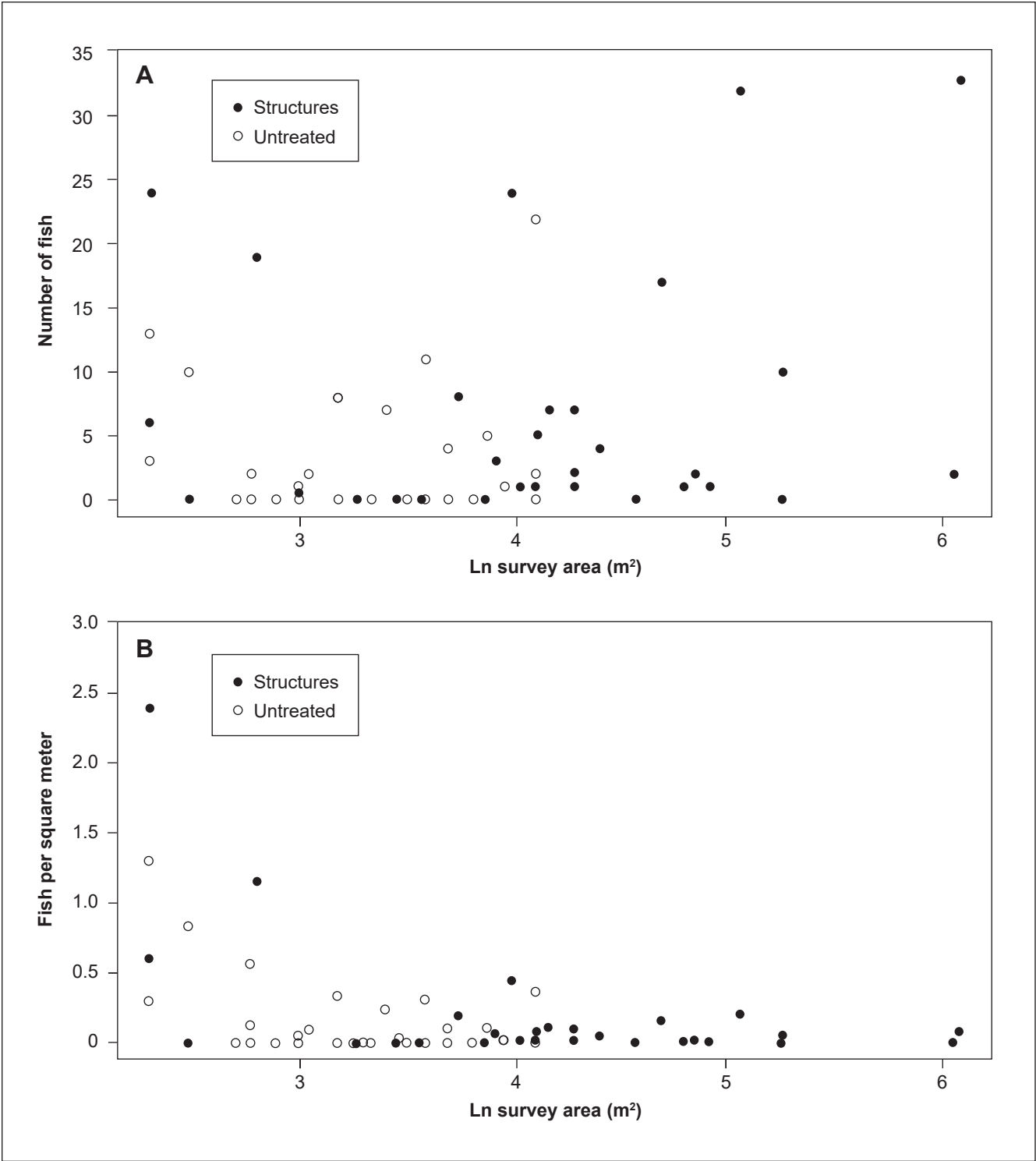


Figure 3—The (A) number and (B) density of young-of-the-year Chinook salmon as a function of the log-transformed survey area from engineered logjam structures (the survey area [black circles] varied from one to three times the pool area) and from untreated habitat (survey area [white circles] varied from 10 to 60 m²), at all three study reaches combined.

Increasing survey area effect on fish density—

With all reaches combined, increasing the sampling area to two to three times the dimensions of a pool created by a restoration structure resulted in a rapid decline in measured Chinook density (fig. 4; table 3). From the nonsignificant term representing ELJ presence in GLM analyses above (table 2), it is clear that varying the survey area extent makes surveys around structures indistinguishable from the untreated habitat surveys. The presence of a significant, negative reach-by-area multiplier interaction term is difficult to explain except that at the Milne reach, untreated habitat had higher density than at the other sites, similar to the mean density in restored pools. This is in contrast with several past years of published data from Milne showing higher fish density at restored pools than unrestored habitat; however, this was likely due, in both current cases, to one or two data points from the randomly selected untreated habitats each day consisting of deep pools with very high densities of fish (see figs. 2 and 3).

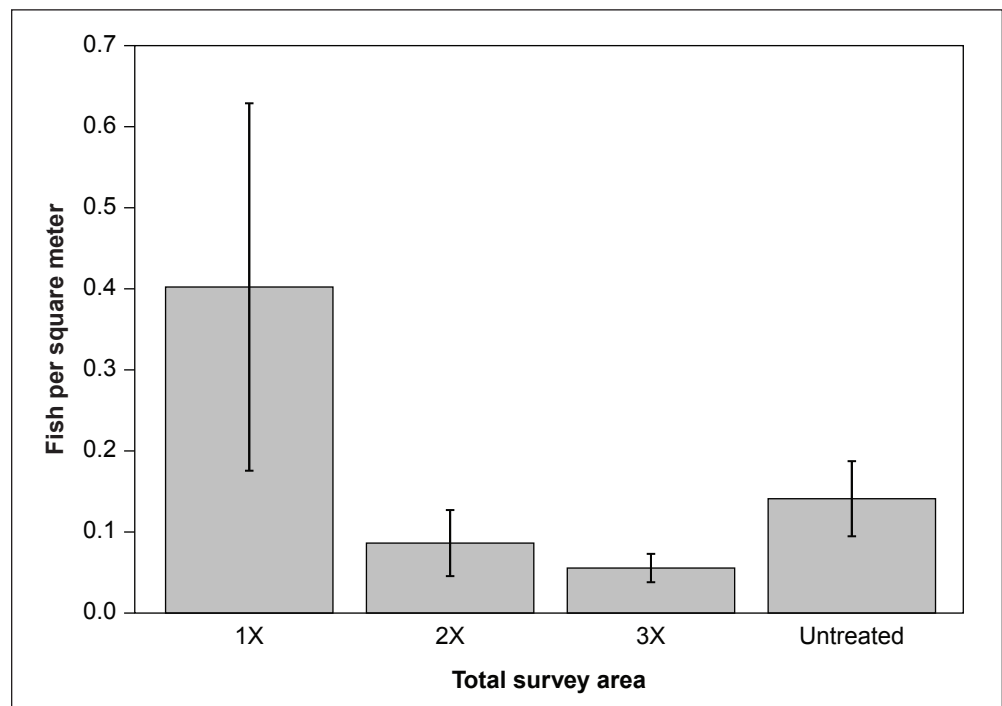


Figure 4—Mean (± 1 SE) young-of-the-year Chinook salmon density observed in snorkel surveys of pools restored with, or created by, engineered logjams (ELJs) in all three study reaches combined. For each ELJ pool, the total survey area was randomly selected as a multiple of 1 (actual pool area only), 2, or 3 times the ELJ pool area, with the pool in the center of the total area. Mean density for all untreated habitat (fig. 2) is provided for reference.

Table 3—Deviance values and significance from analysis of variance (ANOVA) with χ^2 tests on the best fit generalized linear model indicating significant variables determining differences in mean young-of-the-year Chinook salmon density in pools restored or created by engineered logjams (ELJs)

	Coefficient	Degrees of freedom (df)	Deviance	Residual df	Residual deviance	P-value
Reach	NS	2	0.750	28	5.88	0.073
Extent	1×	2	1.20	26	4.69	0.015
Reach × extent		4	1.54	22	3.15	0.030

Note: Extent of the surveyed area around ELJ pools (multiples of 1, 2, or 3) resulted in a significant decline in observed density.

Discussion

Frequently with instream habitat restoration, post-treatment effectiveness studies first show positive results, but with subsequent observations, spatial and temporal variation in the response becomes apparent (Roni et al. 2013, Smokorowski and Pratt 2007). This is particularly true in restoration targeting the spawning streams for Pacific salmon, where positive responses may differ among species (Pess et al. 2012, Polivka et al. 2015). We report here that one cause of inconclusive results is that the scale of posttreatment monitoring might be mismatched with the effects of the treatments. Although installation of ELJs increases the proportion of pool area in a given reach, which may even increase the capacity of the reach (Polivka and Claeson, n.d; Polivka et al. 2015), the observed fish density increase is localized.

The number of individuals observed logically increases with the sampling area, as is the case in the reaches surveyed here. If individuals are evenly distributed across the sampling area, then **density** (individuals/unit area) should remain constant as the sampling area gets larger. This would be the case if restoration structures either had no effect on fish abundance and fish remained relatively evenly distributed among treated and untreated habitat, or if restoration structures increased fish density not only in restored pools but in the reach as a whole. Our samples in untreated habitat of these three reaches in the Entiat River showed that Chinook density declined with increasing area; therefore, individuals were not evenly distributed within reaches. Varying habitat types in reaches, even on the margins (Beechie et al. 2005), makes this result unsurprising. The lack of ELJ effects on fish abundance or density in our variable-area surveys further demonstrates that the density increases in ELJ-enhanced pools are highly localized.

Whole-reach responses are one of the major objectives in IMW programs; therefore, a standard protocol is to conduct effectiveness monitoring surveys at the reach scale (Roni 2005). However, whole-reach surveys might underestimate or overlook the effects of structures. As we have shown here, fish density declines significantly only a few meters away from a restored pool, and widening the survey area around a restored pool quickly reduces density as fish outside that pool are not added in proportion to increased area.

Nevertheless, a reach-scale increase in habitat capacity for fish, as a result of installing ELJs, can be demonstrated by survey methods similar to those used here. Polivka et al. (2015) emphasized the importance of sampling untreated habitat in treated reaches combined with sampling untreated habitat in control reaches with no restoration structures. Comparison of these two categories of untreated habitat indicates whether fish abundance has changed at the reach scale. If pools created or restored by structures have higher fish density than untreated habitat within the same reach, and untreated habitat in that reach has the same average fish density as untreated habitat in untreated reaches, then structures have added capacity to the reach (Polivka and Claeson, n.d.; Polivka et al. 2015), even if the effect is localized. Use of the randomization procedure in multiple (untreated) reference reaches ensures that other physical properties of the habitat are considered for their influence on fish density (Beechie et al. 2005). Untreated reaches in the lower valley segment generally do not differ in mean fish density (Polivka et al. 2015); thus, small changes in substrate, gradient, or riparian condition from reach to reach do not affect comparisons of untreated habitat.

Inconsistent or ambiguous results found in post-restoration effectiveness studies are not necessarily indicative that restoration did not work. Past work has shown that they can result from differences in the positive effect among sites (Smokorowski and Pratt 2007, Whiteway et al. 2010), the timing of sampling surveys (Bond and Lake 2003), species (Pess et al. 2012), or all of the above (Polivka et al. 2015). We have shown here that, in addition to spatiotemporal and species differences, it may also be the result of combining observations of density in relatively few restored pools with those in a large area of untreated habitat in a treated reach. It may simply be necessary to design studies of effectiveness in a way that the scale of effects on fish abundance is reflected in the data. It may also be necessary to examine behavioral (Polivka, n.d.) or life history traits (e.g., survival or growth) (Polivka et al., n.d.; Roni 2005) to augment studies of distribution and abundance for the characterization of positive effects of instream habitat restoration.

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U. S. Equivalents

When you know:	Multiply by:	To get:
Meters (m)	3.28	Feet
Kilometers (km)	.621	Miles
Square meters (m ²)	10.76	Square feet
Degrees Celsius (°C)	1.8 °C + 32	Degrees Fahrenheit

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